

Emission Line Diagnostics of Accretion Flows in Weak-Line Radio Galaxies

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In recent surveys of Radio-loud AGN, a new sub-class of objects, known as Weak-Line Radio Galaxies (WLRGs) has emerged. These radio galaxies have only weak, low-ionization optical emission lines. In the X-ray band, these objects are much fainter and have flatter spectra than broad-line and narrow-line radio galaxies. In these respects, WLRGs are reminiscent of Low Ionization Nuclear Emission Regions (LINERs). We have begun a multi-wavelength study of WLRGs to better understand their possible connection to LINERs and the structure of the accretion flow in both these systems. Here, we present new optical spectra of a sample of WLRGs. We find that 81% of the objects have optical emission-line properties that are similar to LINERs, indicating that these two classes of AGN may be related. Future high resolution X-ray observations of WLRGs will be critical in determining the true nature of the accretion flow in these objects.

1. Introduction

In a survey of southern radio galaxies, Tadhunter *et al.* [1] find that the luminosity of the optical emission lines is strongly correlated with the radio luminosity. An exception are a group of objects, dubbed Weak-Line Radio Galaxies (WLRG), in which the [O III] line is an order of magnitude fainter than in galaxies of comparable radio luminosity and redshift. The low-ionization [O II] and H β lines strengths, however, are not as drastically reduced in WLRGs. This observation *suggests* that the optical emission lines properties of WLRGs may be quite similar to those seen in LINERs.

Even stronger evidence of a connection between WLRGs and accretion powered LINERS is found in the X-ray and UV. In an analysis of ASCA data Sambruna *et al.* [2] find that WLRGs are a distinct class of object, set apart from the other radio-loud AGN¹ by their low X-ray luminosity and flat X-ray spectrum (Fig. 1). Ho [3] also finds that the ASCA spectra of accretion-powered LINERs are somewhat harder than those of radio-quiet AGN. However, it must be noted that the nucleus need not dominate the emission from the galaxy in either WLRGs or LINERs [4]. To de-

termine the true X-ray characteristics of the central engine, it is vitally important to obtain high spatial resolution X-ray data, such as that obtained with *Chandra* and *XMM-Newton*.

The spectral energy distribution (SED) of LINERs shows a significant lack of UV emission. Although it is difficult to measure the SED of WLRGs in the optical-UV band due to the significant absorption column, a similar decrement is measured in at least one WLRG (Fig. 2). Thus there is mounting evidence that the optical emission-line properties as well as the underlying ionizing continuum are similar in WLRGs and LINERs.

Should a connection between the central engines of accretion-powered LINERs and WLRGs be confirmed, this would place important constraints on the structure of the accretion flow in these objects. Any proposed model must be able to explain the behavior of both LINERs and WLRGs. In particular, the engine must be able to produce the kpc-sized radio jets seen in WLRGs.

In this paper we present optical spectra of 11 WLRGs and demonstrate that the emission line properties of WLRGs and LINERs are in fact quite similar to each other. This work represents the *first step* in our multi-wavelength program to better understand the central engines in WLRGs and the possible connection between LINERs and WLRGs.

¹Throughout this paper, radio loud AGN are those associated with powerful double-lobed radio sources with $L_{rad} \geq 10^{25} W/\Omega$ at 5GHz.

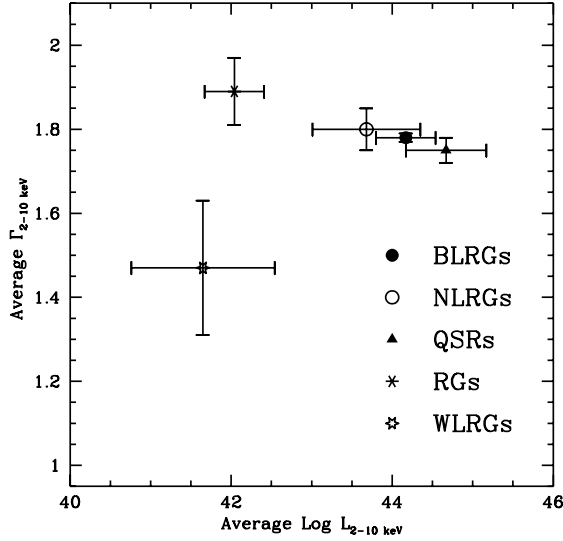


Figure 1. Average 2-10 keV photon index vs 2-10 keV intrinsic luminosity for the different classes of radio sources. WLRGs have a significantly flatter average slope than the other sources [2].

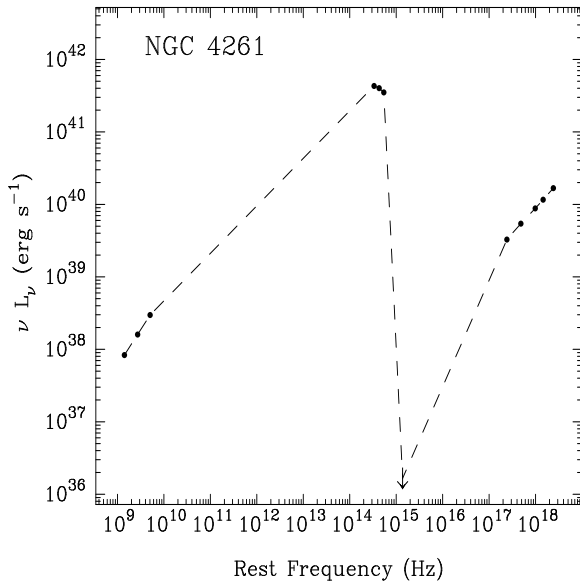


Figure 2. The SED of the WLRG NGC 4261. Note the deficit of UV emission [2].

2. Optical Data

The data set used here consists of spectra of 11 WLRGs, as listed in Tab. 1. The spectra were obtained at KPNO 2.1m, CTIO 1.5m and the MDM Observatory 2.4m telescopes. In order to measure the strengths of the emission lines, the starlight from the host galaxy must be subtracted. This was done by fitting a template elliptical galaxy to the spectrum (adjusting the redshift and Galactic reddening to match those of the object) and then subtracting the fit from the object spectrum. An example of the template subtraction is shown in Fig. 3. Some residual continuum remains, which was subtracted in the neighborhood of each emission line. Each emission line was then fitted with a Gaussian profile. Finally, the fluxes measured from the model profiles were used to place WLRGs in several classification schemes for emission line galaxies, as shown in Fig. 4 [5, 6]. These diagnostics have been developed *observationally* over the past 20 years, as they clearly separate different classes of emission line galaxies.

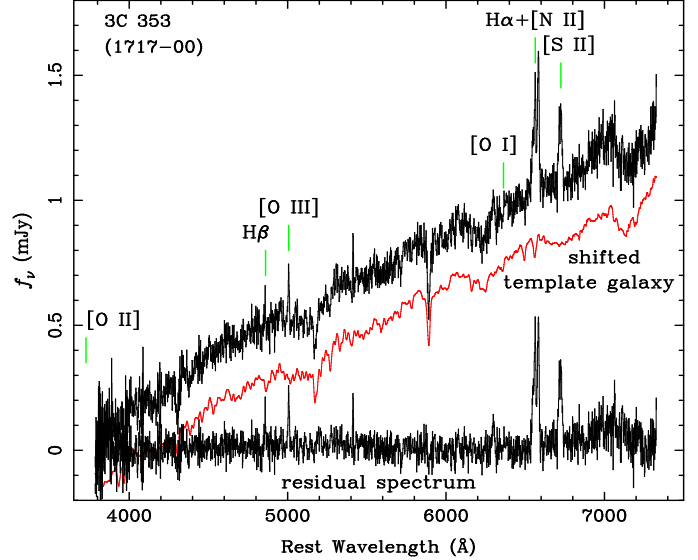


Figure 3. Example of galaxy template subtraction for 3C 353, which is an average spectrum in terms of initial line strength, S/N, and resolution. Top: Original spectrum, Middle: Template, Bottom: Residuals, from which the line fluxes are measured. Important diagnostic emission lines are labeled.

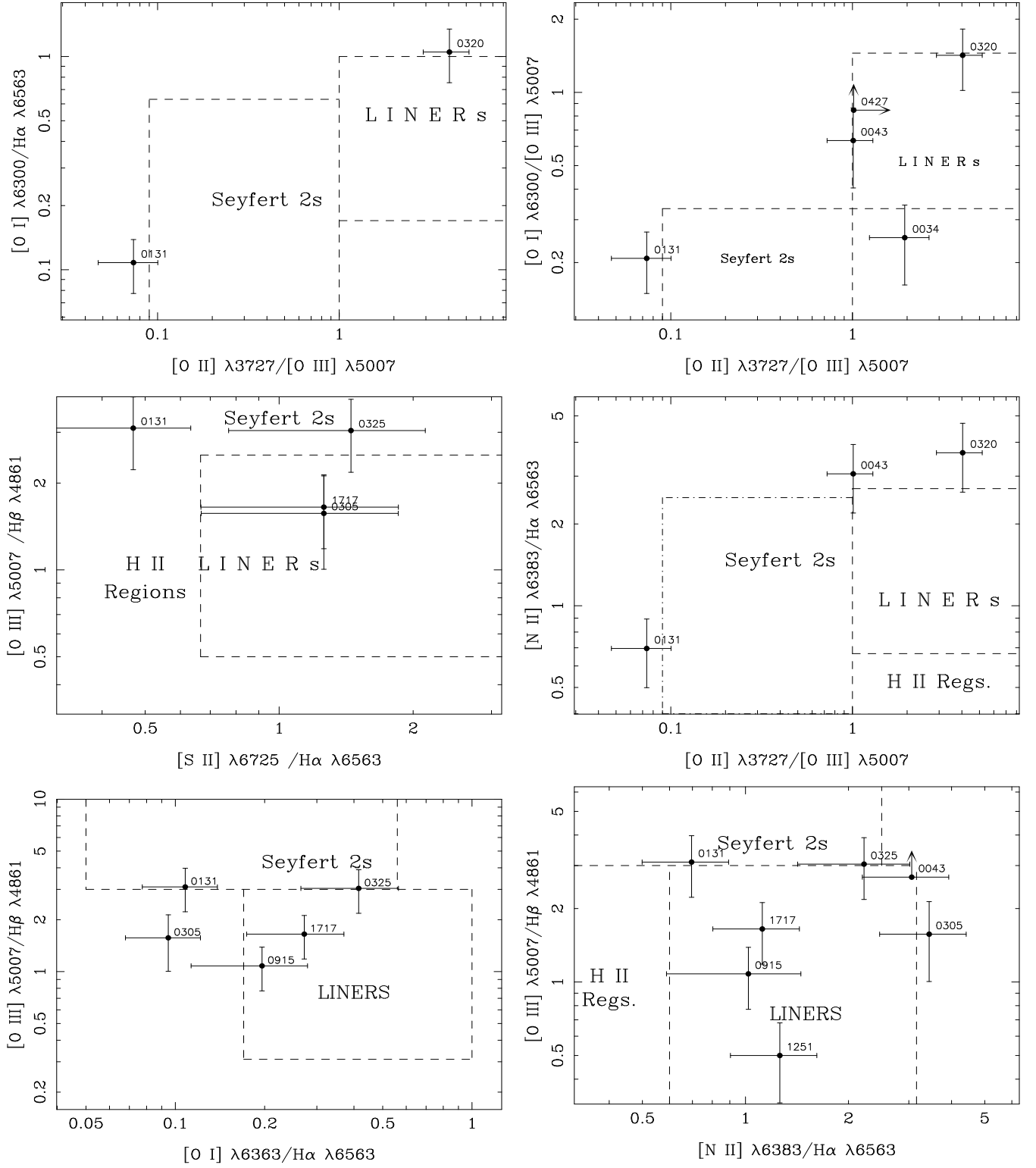


Figure 4. Diagnostic diagrams for the 11 WLRGs. The regions generally occupied by LINERs, Seyferts, and H II regions are designated. See [5, 6] for definitions of the classification scheme.

Table 1
Weak-Line Radio Galaxies in the Current Sample

IAU Name	Other Names *	z	X-ray Obs.
0034-01	3C 15 ^C	0.073	
0043-42	^C	0.117	
0131-36	NGC 612 ^S	0.030	ASCA
0305+03	3C 78, NGC 1218 ^C	0.029	SAX
0320-37	For A, NGC 1316 ^C	0.006	ASCA
0325+02	3C 88 ^C	0.031	SAX
0427-53	^L	0.040	
0625-35	OH-342 ^S	0.055	
0915-11	Hyd A, 3C 218 ^L	0.054	Chandra
1251-12	3C 278 ^L	0.016	
1717-00	3C 353 ^L	0.030	ASCA

* L=Liner, S=Seyfert, C=Composite

3. Results

All of the objects are classified in at least one of the six 2D diagnostic diagrams (Fig. 4) with the exception of OH-342. We divide the objects into two main groups:

Pure LINERs: These objects fall within the LINER region in all diagrams for which the necessary lines were measured.

Composite LINERs: While showing evidence of LINER-like emission in some diagrams, several objects are also classified as a Seyfert and/or H II region in others. Other objects consistently straddle the boundary between LINERs and Seyferts or H II regions. All of these objects are classified as composites.

Most of the WLRGs (81%) in our sample are classified as either a pure (36%) or composite (45%) LINER (Tab. 1). NGC 612 is classified as a Seyfert and OH-342, not shown, is likely to be a Seyfert based upon its large $[\text{O III}]/\text{H}\beta$ ratio.

4. Conclusions, Discussion, and Future Work

We have shown that the optical emission line properties of most WLRGs are similar to LINERs. Several objects in our sample are classified as composites due to the large error bars on the measurements. Better optical spectra of some objects are needed to solidify the classification. We have obtained additional spectra, including new objects, which we are currently reducing and ana-

lyzing. High spatial resolution spectroscopy from the ground or with HST will also be helpful in this respect.

However, it is likely that WLRG, like LINERs are a diverse group of objects. The central engine need not dominate the energetics of the galaxy and other excitation sources such as a hot stars, shocks, or cooling flows may play an important role in the formation of the emission lines. In Hyd A, for example, UV observations reveal a circumnuclear ring of star formation [7, 8].

To determine whether WLRGs and LINERs are physically similar, it is necessary to study the SEDs of WLRGs. In the UV and X-ray regimes this is quite challenging. There appears to be a deficit of UV photons in WLRGs (Fig. 2), but the high absorption column ($\text{NH} \geq 10^{23} \text{cm}^2$ in some cases) makes a UV flux measurement, or even a useful upper limit, virtually impossible to obtain. Until recently, the nuclear region of WLRGs and LINERs have not been spatially resolved in X-rays, making it impossible to truly determine the X-ray portion of the SED. A recent *Chandra* observation of Hydra A [4] has demonstrated that while there can be several sources of x-ray emission in WLRGs, the nucleus can be successfully isolated from the host galaxy. Considering the difficulty of the UV observations, studies of WLRGs in the X-ray regime are the best hope for constraining their SED.

The results of this work strongly suggest that LINERs and WLRGs may be intimately related. More detailed studies in the UV and particularly X-ray will solidify this relationship and lead to an improved understanding of the structure of the accretion flow in both LINERs and WLRGs.

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